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MODELING OF EROSIVE COMBUSTION PRODUCTS AFFECTING THE 120-MM M256/M829A2 GUN SYSTEM

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13. ABSTRACT (Maximum 200 words)

The MACE gun barrel erosion code is used to thermochemically model erosive combustion products affecting the 0.005-inch high contraction (HC) chromium plated A723 steel 120-mm M256/ambient temperature-conditioned M829A2 gun system for a single-round firing scenario. The HC chromium plate, the subsurface A723 steel substrate at HC chromium crack bases, and bare A723 steel are evaluated. This gun erosion analysis includes the standard interior ballistics gun code (XNOVAKTC), the standard nonideal gas-wall thermochemical rocket code modified for guns (CCET), the standard mass addition boundary layer rocket code modified for guns (MABL), and the standard wall material ablation conduction code modified for guns (MACE). Specifically, this new variation of the gun erosion analysis uses MACE wall temperatures as a function of time/position/depth, as well as their associated gas pressures as a function of time/position to thermochemically compute differences in combustion products for the various reacting and nonreacting walls allowing erosive combustion products to be identified. Identification of erosive combustion products by comparative modeling between proposed and present propellant formulations or between a propellant formulation with and without additives may benefit current U.S. Army/Navy programs that attempt to lower propellant flame temperature and/or propellant erosion. Carbon dioxide, water, and carbon monoxide are the identified erosive combustion products for this gun system.

14. SUBJECT TERMS

Gun Erosion Modeling, Erosive Combustion Products, 120-mm M256 Barrels, M829A2 Rounds

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INTRODUCTION

A unified computer model for predicting thermochemical erosion in gun barrels was first described by Dunn et al. in 1995 (ref 1) using the following codes:

- Standard heat transfer modified by mass addition to boundary layer rocket code modified for guns (MABL)

- Standard nonideal gas-wall thermochemical rocket code modified for guns (CCET)

- Standard wall material ablation conduction erosion rocket code modified for guns (MACE)

Additionally, this gun barrel erosion model requires the standard interior ballistics gun code (XNOVAKTC) (ref 2) results for input. Many ADPA Tri-Service sponsored gun erosion meetings have implied a thermochemical erosion mechanism for various gun systems, and U.S. Army experimental data support the existence of gun barrel oxidation (refs 3,4). Practical gun barrel design should protect against the lower temperature thermochemical erosion and remain below the higher temperature thermal erosion. Practical gun barrel erosion modeling should be kept on-track by actual interior ballistics, boundary layer, thermochemical, and material analysis systems data to the degree they are available. These models should evolve as patterns are identified from multiple systems.

Identification of erosive combustion products by comparative modeling between proposed and present propellant formulations or between a propellant formulation with and without additives may benefit current U.S. Army/Navy programs that attempt to lower propellant flame temperature and/or propellant erosion. This report attempts to quantitatively identify erosive combustion products affecting the 0.005-inch high contraction (HC) chromium plated A723 steel 120-mm M256/ambient temperature-conditioned M829A2 gun system for a single-round firing scenario. The HC chromium plate, the subsurface A723 steel substrate at HC chromium crack bases, and bare A723 steel are evaluated.

PROCEDURE

The initial modeling steps of erosive combustion products affecting the 0.005-inch HC chromium plated A723 steel 120-mm M256/ambient temperature-conditioned M829A2 gun system for a single-round firing scenario at 27 and 61 inches from the rear face of the tube (RFT) included:

- XNOVAKTC interior ballistics gun code for gas pressure, gas temperature, and gas velocity core flow predictions (ref 2)

- MABL mass addition to boundary layer gun code for recovery enthalpy and cold wall heat flux predictions (ref 1)

- CCET gas-wall thermochemistry gun code for inert wall enthalpy, reacting wall enthalpy, and ablation potential predictions (ref 1)

- MACE material ablation conduction erosion gun code for wall temperature profiles and wall erosion profiles (ref 1)

The final modeling steps for this analysis included:

- MACE predictions of gas pressure and ablating wall temperature regions versus time for surface HC chromium plate, surface A723, and subsurface A723 steel substrate at HC chromium crack bases

- CCET predictions of inert and reacting surface/interfacial A723 wall combustion products using the respective gas pressure and wall temperature data mapped from MACE predictions

- A comparison of the CCET predictions of inert and reacting surface/interfacial A723 wall combustion products to determine the erosive combustion products

Experimental data used for this gun system model calibration included:

- Pressure gauge data for XNOVAKTC gas pressure

- Radar for XNOVAKTC gas velocity

- Kinetic rate data for CCET chemistry where gas-wall temperatures of reaction were determined from M256 barrels that fired M829A2 rounds

- Subsurface metallographic data for CCET chemistry

- Surface borescope data for MACE ablation/conduction/erosion

- Subsurface metallographic data for MACE ablation/conduction/erosion

RESULTS AND DISCUSSION

Figure 1 summarizes the XNOVAKTC interior ballistic and MABL boundary analyses of ambient temperature-conditioned M829A2 rounds in the 120-mm M256 gun. These analyses provide maximum values of gas pressure (P_{gas}), gas temperature (T_{gas}), gas velocity (V_{gas}), recovery enthalpy (H_r), and cold wall heat flux (Q_{cw}) at axial positions 27 and 61 inches from the RFT. Experimental P_{gas} and V_{gas} data at selected positions were used to calibrate the interior ballistic analysis, which was the starting point of the overall analysis and subsequently provided input to the boundary layer analysis.

Figure 2 summarizes the CCET thermochemical analysis for the gun system also at 27 and 61 inches from RFT. The analysis provides reacting wall enthalpy (H_{wall}), and ablation potential (B_a) for the HC chromium and Fe/A723 wall materials as a function of wall temperature (T_{wall}). Experimental kinetic rate function data were used to transform the chemical equilibrium analysis into a partial chemical kinetic analysis. Experimental data were also collected from M256 subsurface metallographic analysis. The HC chromium wall passivatingly oxides at ~2000°K, the maximum T_{wall} for this gun system is ~2000°K, and the ~2130°K HC chromium melting point is not applicable. The Fe/A723 wall oxides in a more rapid expansive flaking manner at ~1055°K, this oxide melts at ~1640°K, maximum T_{wall} for this gun system is ~1640°K, and the ~1810°K Fe/A723 melting point is not applicable.

Figure 3 summarizes initial/final borescope data and estimated shot-by-shot interim borescope data for A723 subsurface exposure through HC chromium plate cracks, again for the gun system at 27 and 61 inches from RFT. Final experimental data were collected from some cleaned 120-mm M256 tubes using a magnifying borescope with a calibrated scale to measure average HC chromium platelet widths at the desired positions for a typical M256 retired low round group (LRG) averaging a life of ~280 rounds and a typical M256 retired high round group (HRG) averaging a life of ~510 rounds. Initial experimental data have been collected from many cleaned 120-mm M256 tubes using a magnifying borescope with a calibrated scale to measure average HC chromium platelet widths at the desired positions. Limited interim experimental data between ten and fifty rounds have also been collected from some cleaned 120-mm M256 tubes with a similar round distribution using a magnifying borescope with a calibrated scale to measure average HC chromium platelet widths at the desired positions. Percent A723 subsurface exposure is calculated by

$$\textit{\% A723 Subsurface Exposure} = 100[(W_{tc}\,W_{ta}) - (W_{mpc}\,W_{mpa}\,N_c\,N_a)]/(W_{tc}\,W_{ta}) \quad (1)$$

where W_{tc} = total width circumferentially, W_{ta} = total width axially, W_{mpc} = mean platelet width circumferentially adjusted for pitting, W_{mpa} = mean platelet width axially adjusted for pitting, N_c = number of plates circumferentially, and N_a = number of plates axially. Experimental data were also collected from M256 subsurface metallographic analysis. HC chromium outgassing of some nonmetallics and compression result in its shrinkage. Heat checking provides the increase in A723 subsurface exposure. M256 tube life for the M829A2

round appears to be inversely proportional to A723 subsurface exposure. HC chromium plate has fine cracking and finite shrinkage when manufactured prior to firing.

Figure 4 summarizes the MACE material ablation conduction erosion analysis for the gun system at 27 inches from RFT based on input from Figures 1 through 3 for A723 P_{gas} and ablating wall temperature (T_{wall}) regions (>1055°K) versus time (*t*) for surface A723, interfacial LRG A723, and interfacial HRG A723. Although neither HC chromium nor A723 are melting, gas wash thermochemically degrades both interfacial A723 at HC chromium heat-checked crack bases and also fully exposed A723. Both interface groups have lower T_{wall} values due to 0.005-inch HC chromium plate. The HC chromium T_{wall} curve is absent from this figure since it does not ablate.

Figure 5 shows the CCET thermochemical analysis inert and reacting interfacial chromium/A723 wall combustion products for the gun system's HRG at 27 inches from RFT using the respective P_{gas} and T_{wall} data pairs mapped from Figure 4. Translating from the inert to the reacting Fe/A723 wall case: a molar portion of the mostly iron wall becomes an equal molar portion of iron oxide; carbon dioxide (or its precursors) appears to be an erosive combustion product, since it decreases providing much of the wall oxygen; carbon monoxide (or its precursors) appears to be an erosive combustion product, since it decreases providing some of the wall oxygen; water (or its precursors) appears to be an erosive combustion product, since it decreases providing some of the wall oxygen. This is compensated by methane, hydrogen, and graphite (or their precursors), which appear to be nonerosive combustion products, since they increase to adjust the C, H, O balance. Calculations show that it takes ~460 M829A2 HRG rounds to gas wash onset at 27 inches from RFT.

Figure 6 shows the CCET thermochemical analysis inert and reacting interfacial chromium/A723 wall combustion products for the gun system's LRG at 27 inches from RFT using the respective P_{gas} and T_{wall} data pairs mapped from Figure 4. Translating from the inert to the reacting Fe/A723 wall case: a molar portion of the mostly iron wall becomes an equal molar portion of iron oxide; carbon dioxide (or its precursors) appears to be an erosive combustion product, since it decreases providing much of the wall oxygen; carbon monoxide (or its precursors) appears to be an erosive combustion product, since it decreases providing some of the wall oxygen; water (or its precursors) appears to be an erosive combustion product, since it decreases providing some of this wall oxygen. This is compensated by methane, hydrogen, and graphite (or their precursors), which appear to be nonerosive combustion products, since they increase to adjust the C, H, O balance. Calculations show that it takes ~220 M829A2 LRG rounds to gas wash onset at 27 inches from RFT.

Figure 7 shows the CCET thermochemical analysis inert and reacting fully exposed A723 wall (due to HC chromium loss) combustion products for the gun system at 27 inches from RFT using the respective P_{gas} and T_{wall} data pairs mapped from Figure 4. Translating from the inert to the reacting Fe/A723 wall case: a molar portion of the mostly iron wall becomes an equal molar portion of iron oxide; carbon dioxide (or its precursors) appears to be an erosive combustion product, since it decreases providing much of the wall oxygen; water (or its precursors) appears

to be an erosive combustion product, since it decreases providing some of the wall oxygen. This is compensated by methane, carbon monoxide, hydrogen, and graphite (or their precursors), which appear to be nonerosive combustion products, since they increase to adjust the C, H, O balance. Calculations show that it takes ~50 M829A2 rounds from gas wash onset to erosion condemnation at 27 inches from RFT.

Figure 8 summarizes the MACE material ablation conduction erosion analysis for the gun system at 61 inches from RFT based on input from Figures 1 through 3 for A723 P_{gas} and ablating wall temperature (T_{wall}) regions (>1055°K) versus time (*t*) for surface A723, interfacial LRG A723, and interfacial HRG A723. Although neither HC chromium nor A723 are melting, gas wash thermochemically degrades both interfacial A723 at HC chromium heat-checked crack bases and also fully exposed A723. In addition, metal oxide melting enhances ablation for the fully exposed A723. Both interface groups have lower T_{wall} values due to 0.005-inch HC chromium plate. The HC chromium T_{wall} curve is absent from this figure since it does not ablate.

Figure 9 shows the CCET thermochemical analysis inert and reacting interfacial chromium/A723 wall combustion products for the gun system's HRG at 61 inches from RFT using the respective P_{gas} and T_{wall} data pairs mapped from Figure 8. Translating from the inert to the reacting Fe/A723 wall case: a molar portion of the mostly iron wall becomes an equal molar portion of iron oxide; carbon dioxide (or its precursors) appears to be an erosive combustion product, since it decreases providing much of the wall oxygen; carbon monoxide (or its precursors) appears to be an erosive combustion product, since it decreases providing some of the wall oxygen; water (or its precursors) appears to be an erosive combustion product, since it decreases providing some of the wall oxygen. This is compensated by methane, hydrogen, and graphite (or their precursors), which appear to be nonerosive combustion products, since they increase to adjust the C, H, O balance. Calculations show that the number of M829A2 HRG rounds to gas wash onset exceeds the gun's life at 61 inches from RFT.

Figure 10 shows the CCET thermochemical analysis inert and reacting interfacial chromium/A723 wall combustion products for the gun system's LRG at 61 inches from RFT using the respective P_{gas} and T_{wall} data pairs mapped from Figure 8. Translating from the inert to the reacting Fe/A723 wall case: a molar portion of the mostly iron wall becomes an equal molar portion of iron oxide; carbon dioxide (or its precursors) appears to be an erosive combustion product, since it decreases providing much of the wall oxygen; carbon monoxide (or its precursors) appears to be an erosive combustion product, since it decreases providing some of the wall oxygen; water (or its precursors) appears to be an erosive combustion product, since it decreases providing some of the wall oxygen. This is compensated by methane, hydrogen, and graphite (or their precursors), which appear to be nonerosive combustion products, since they increase to adjust the C, H, O balance. Calculations show that the number of M829A2 LRG rounds to gas wash onset exceeds the gun's life at 61 inches from RFT.

Figure 11 shows the CCET thermochemical analysis inert and reacting fully exposed A723 wall (due to HC chromium loss) combustion products for the gun system at 61 inches from RFT using the respective P_{gas} and T_{wall} data pairs mapped from Figure 8. Translating from the

inert to the reacting Fe/A723 wall case: a molar portion of the mostly iron wall becomes an equal molar portion of iron oxide; carbon dioxide (or its precursors) appears to be an erosive combustion product, since it decreases providing about half of the wall oxygen; water (or its precursors) appears to be an erosive combustion product, since it decreases providing about half of the wall oxygen. This is compensated by methane, carbon monoxide, hydrogen, and graphite (or their precursors), which appear to be nonerosive combustion products, since they increase to adjust the C, H, O balance. Calculations show that it takes <50 M829A2 rounds from gas wash onset to erosion condemnation at 61 inches from RFT. However, HC chromium removal is not achieved thermochemically and requires mechanical removal.

Figures 5 through 7 and 9 through11 reveal that combustion products with less than 0.001 mole fraction are omitted. The transition from lower P_{gas}-lower T_{wall} to peak P_{gas}-peak T_{wall} back to lower P_{gas}-lower T_{wall} has a complex nonlinear effect on its mole fraction values for a given combustion product species above the ~1055°K ablation threshold. These values are often vastly different from those calculated by a nonideal gas adiabatic constant volume thermochemical equilibrium analysis (mole fractions: $CO = 0.37$, $CO_2 = 0.13$, $H_2 = 0.10$, $H_2O = 0.27$, $N_2 = 0.13$), since only the upper P_{gas}-T_{wall} region is highlighted here and modified by kinetic rate functions. When iron oxide is formed at the fully exposed A723 surface and this oxide melts, then a much faster ablating action occurs. When sufficient iron oxide is formed at the HC chromium/A723 interface but fails to melt, iron oxide occupies a larger volume than the original iron and pushes up the chromium platelet from all four sides. Eventually a planar crack propagates across the interface and the HC chromium platelet spalls. If iron oxide is formed at the HC chromium/A723 interface and this oxide melts, then a much faster spalling action occurs.

Identification of erosive combustion products by comparative modeling between proposed and present propellant formulations or between a propellant formulation with and without additives may benefit current U.S. Army/Navy programs that attempt to lower propellant flame temperature and/or propellant erosion. Carbon dioxide, water, and carbon monoxide are the identified erosive combustion products for this gun system. For interfacial Fe/A723 at 27 and 61 inches from RFT, nearly similar combustion products, coupled with the area 27 inches from RFT mapping higher ablating P_{gas}-T_{wall} pairs from Figure 2, result in an order of magnitude more interfacial erosion. For fully exposed Fe/A723 at 27 and 61 inches from RFT, the area 61 inches from RFT has slightly less oxidizing combustion products that are offset by it mapping higher ablating P_{gas}-T_{wall} pairs from Figure 2, resulting in more than twice the surface erosion.

REFERENCES

1. Dunn, S., Sopok, S., Coats, D., O'Hara, P., Nickerson, G., and Pflegl, G., "Unified Computer Model for Predicting Thermochemical Erosion In Gun Barrels," *Proceedings of 31st AIAA Propulsion Conference*, San Diego, CA, July 1995.

2. Gough, P., "The XNOVAKTC Code," Paul Gough Associates, Portsmouth, NH, 1990.

3. Picard, J., Ahmad, I., and Bracuti, A., *Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposiums*, U.S. Army ARDEC/ADPA, Dover, NJ, 1970, 1972, 1977, and 1982.

4. Alkidas, A., Morris, S., Christoe, C., Caveny, L., and Summerfield, M., "Erosive Effects of Various Pure and Combustion-Generated Gases on Metals - Part II," U.S. Army Materials and Mechanics Research Center, Watertown, MA, 1977; see also Part I, 1975.

Figure 1 - XNOVAKTC Maximum Pgas, Tgas, Vgas & MABL Maximum Hr, Qcw - For M829A2amb at 27" & 61" RFT

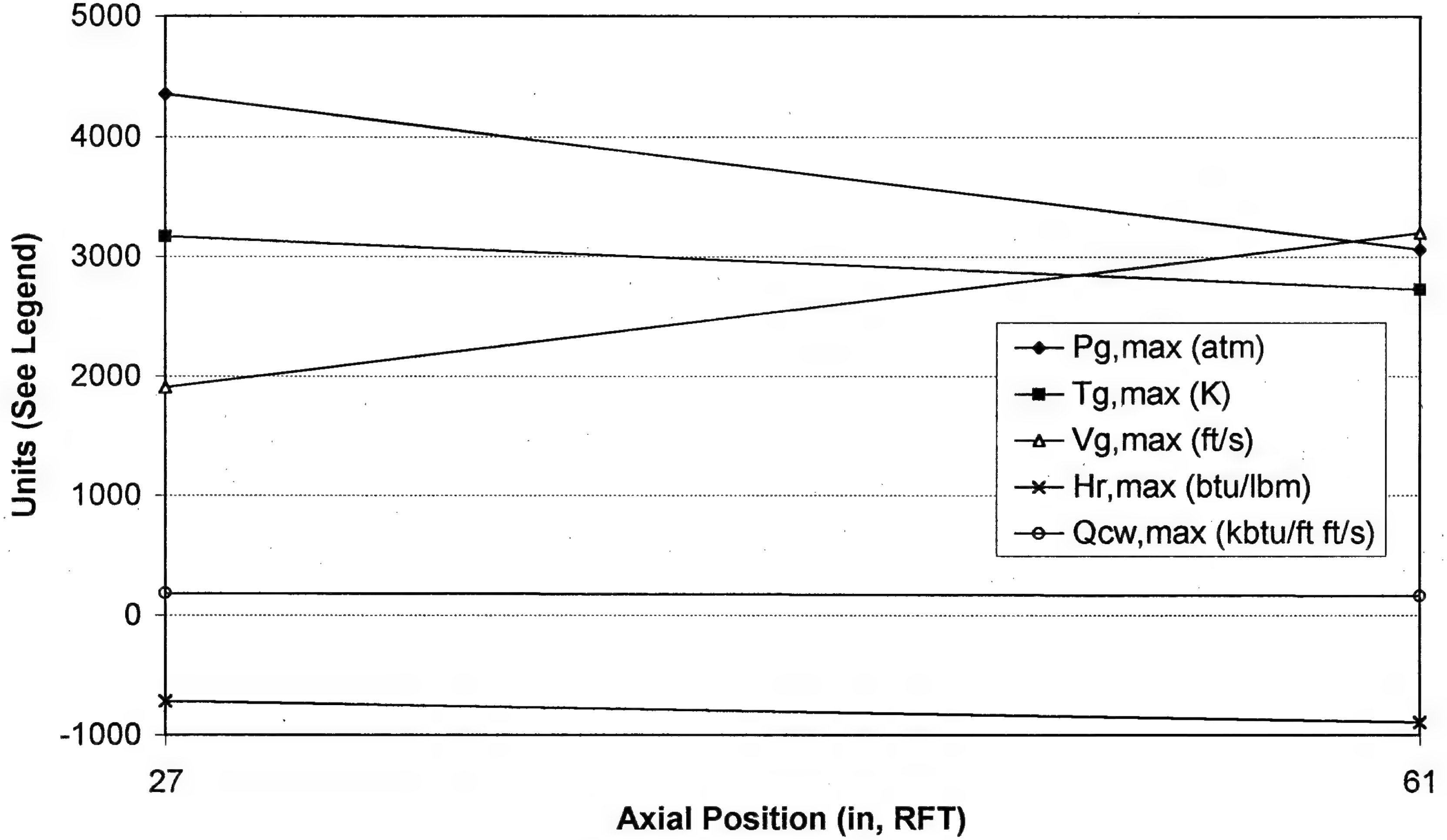
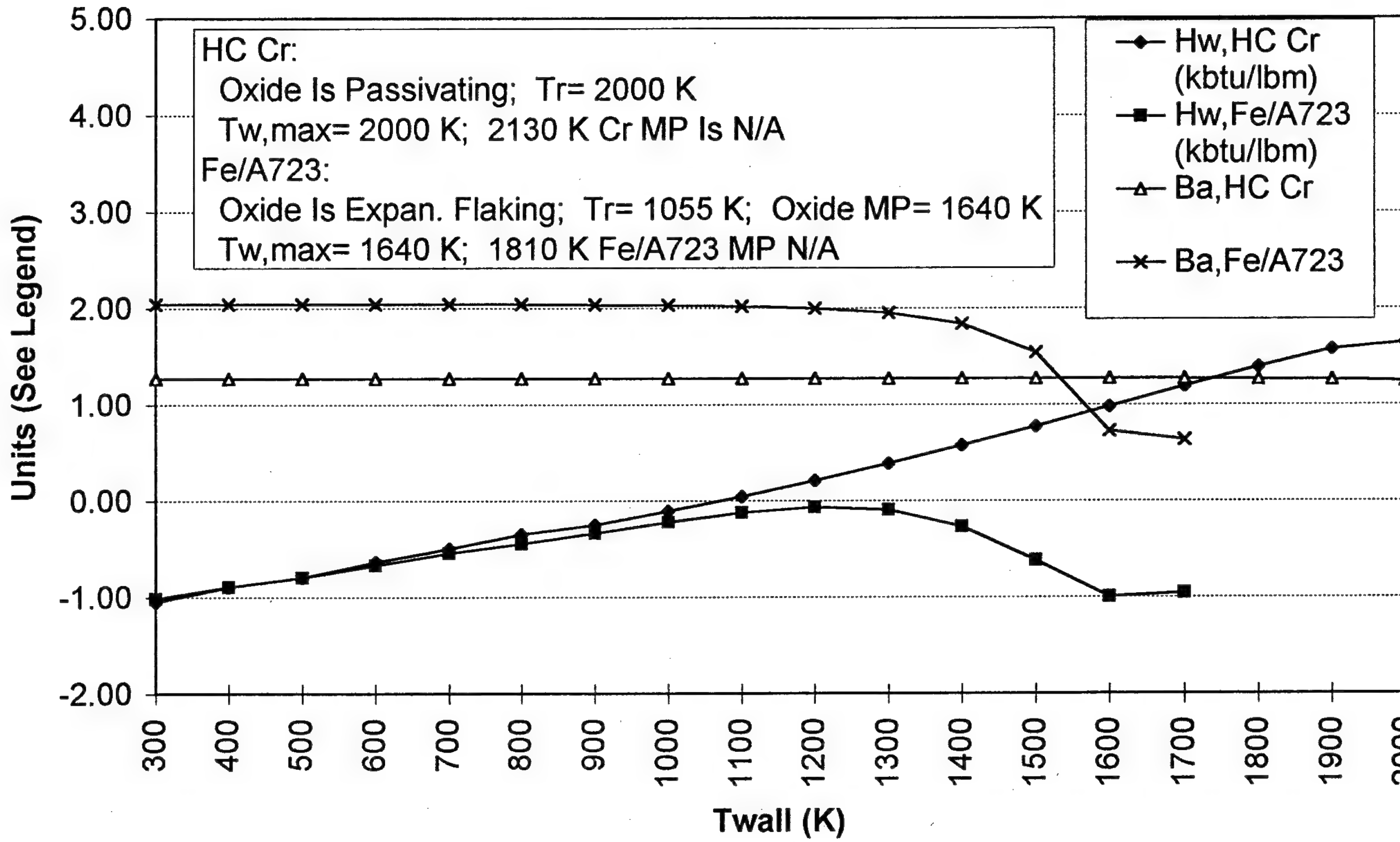


Figure 2 - CCET Hwall & Ablation Potential vs Twall - For M829A2amb At 27" & 61" RFT



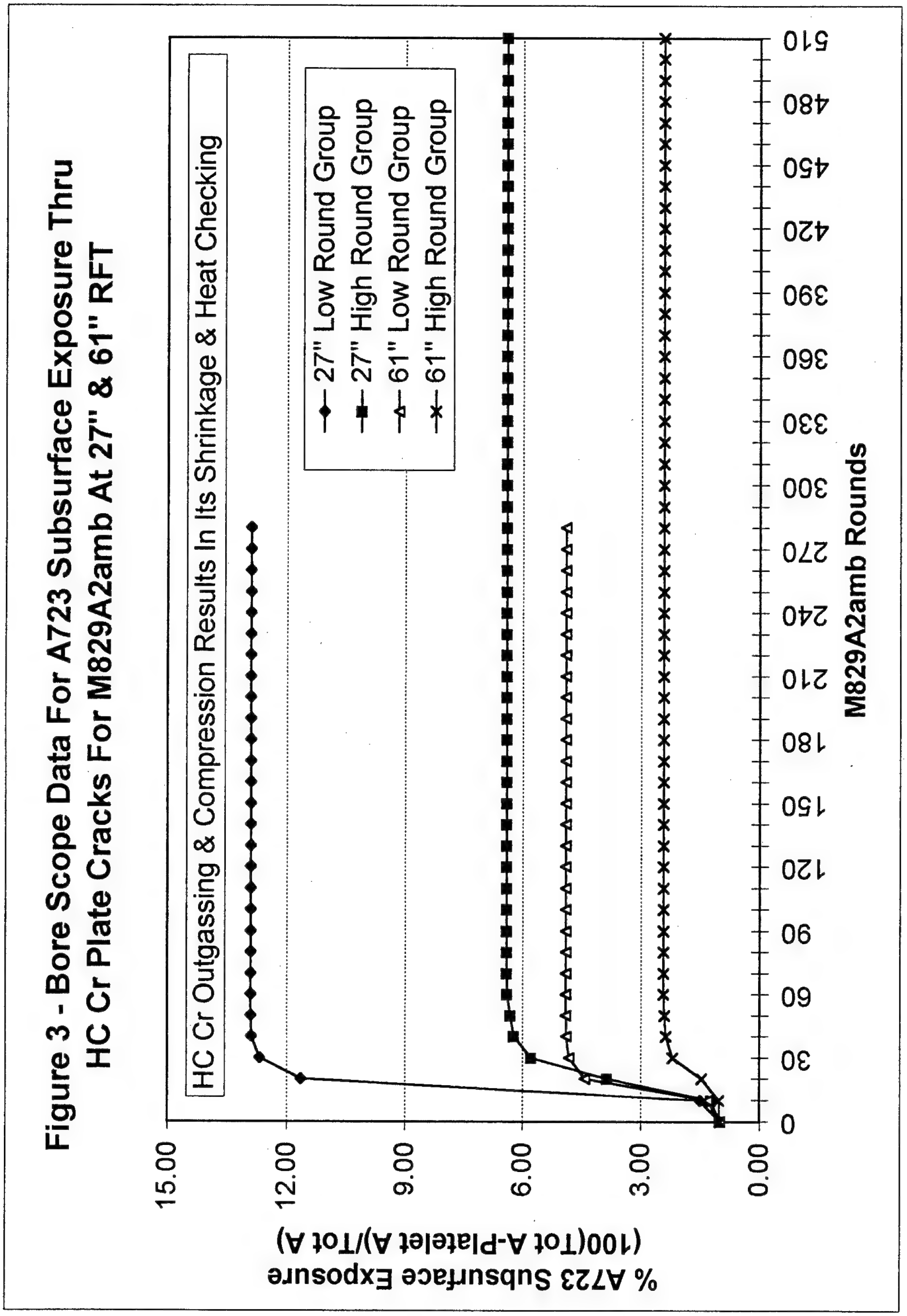
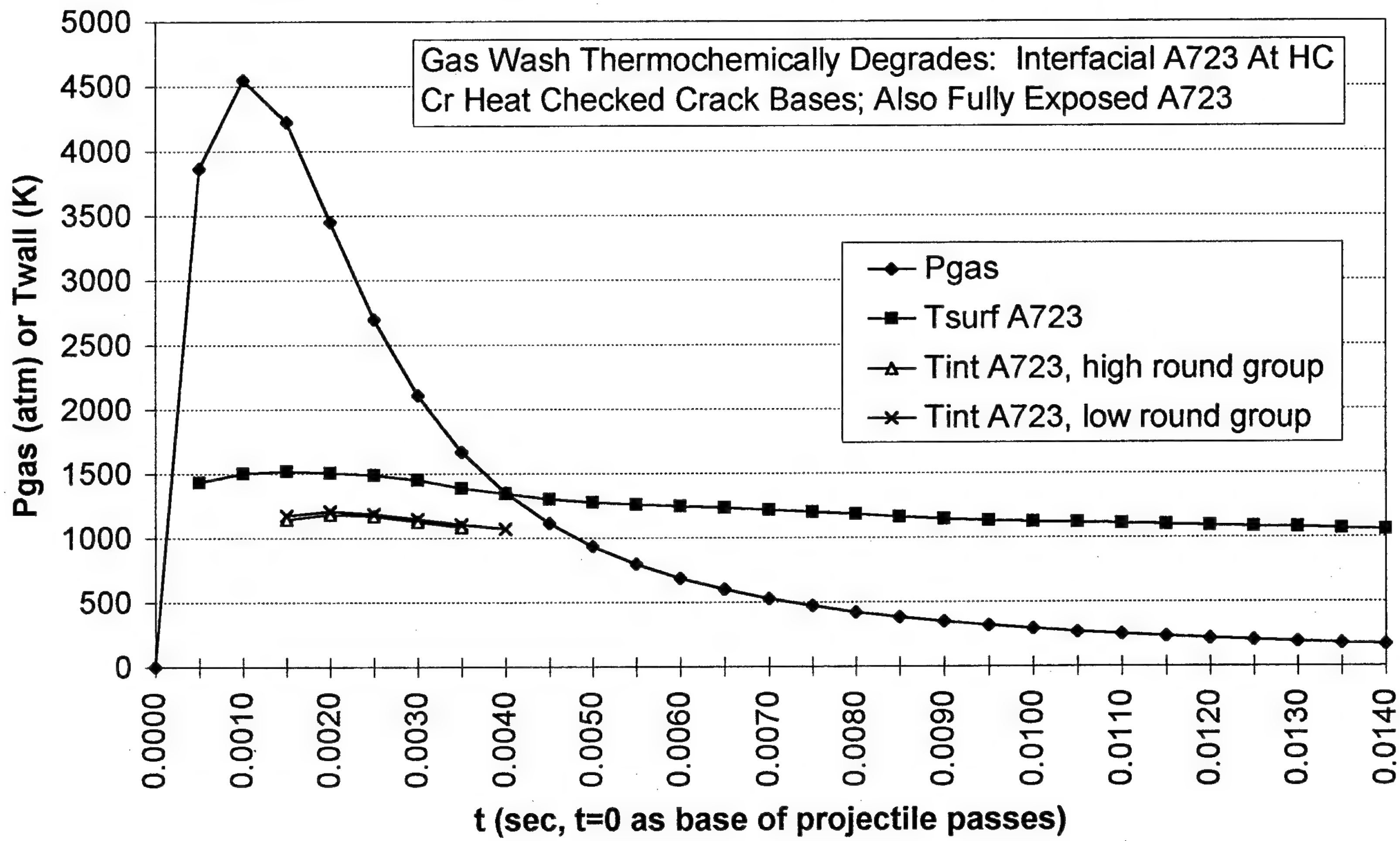


Figure 3 - Bore Scope Data For A723 Subsurface Exposure Thru
HC Cr Plate Cracks For M829A2amb At 27" & 61" RFT
HC Cr Outgassing & Compression Results In Its Shrinkage & Heat Checking
27" Low Round Group
27" High Round Group
61" Low Round Group
61" High Round Group
% A723 Subsurface Exposure
(100(Tot A-Platelet A)/Tot A)
15.00
12.00
9.00
6.00
3.00
0.00
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
M829A2amb Rounds

Figure 4 - MACE A723 Pgas & Ablating Twall Regions vs t For M829A2amb Surf., Int. LRG, & Int. HRG A723 At 27" RFT



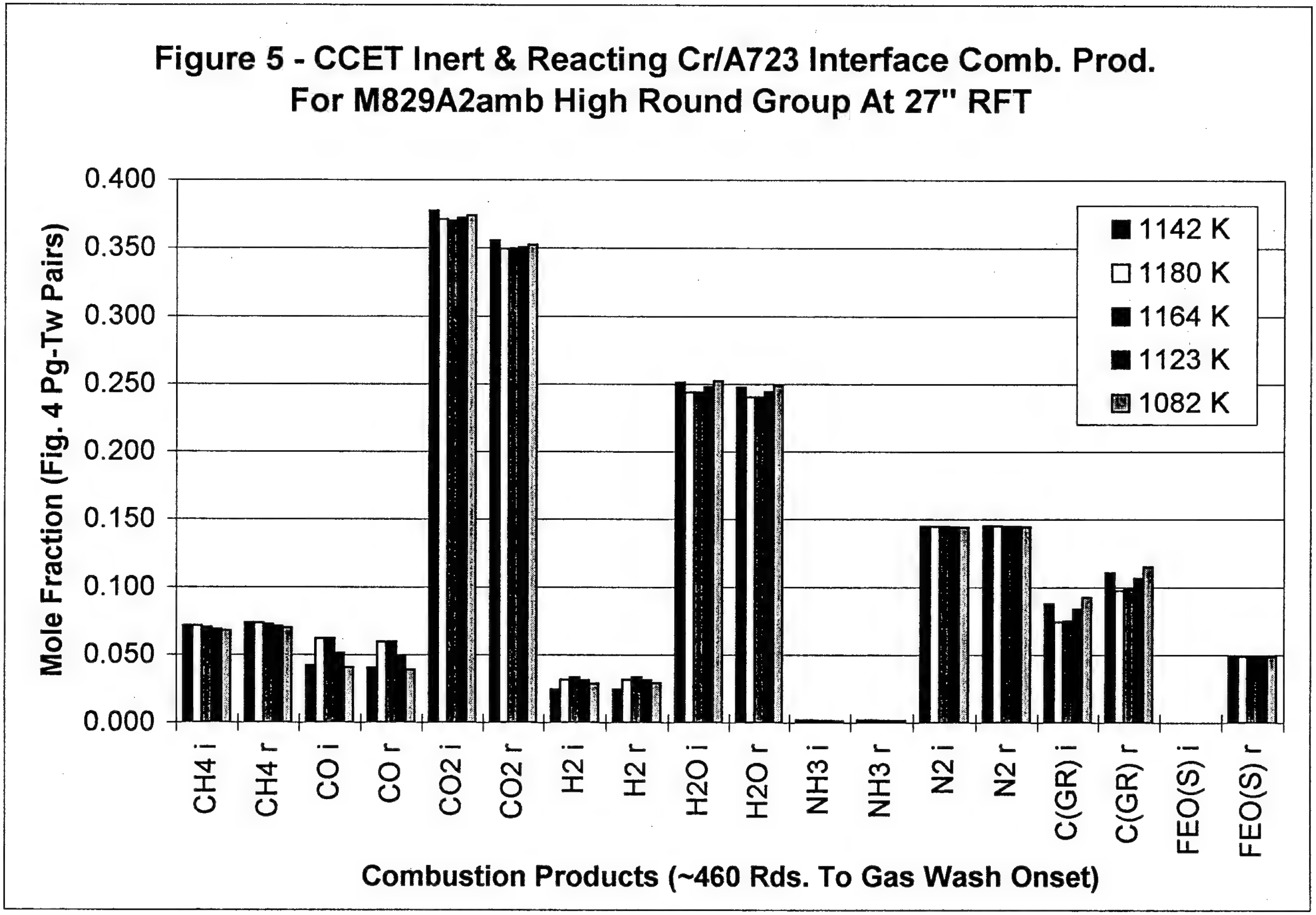
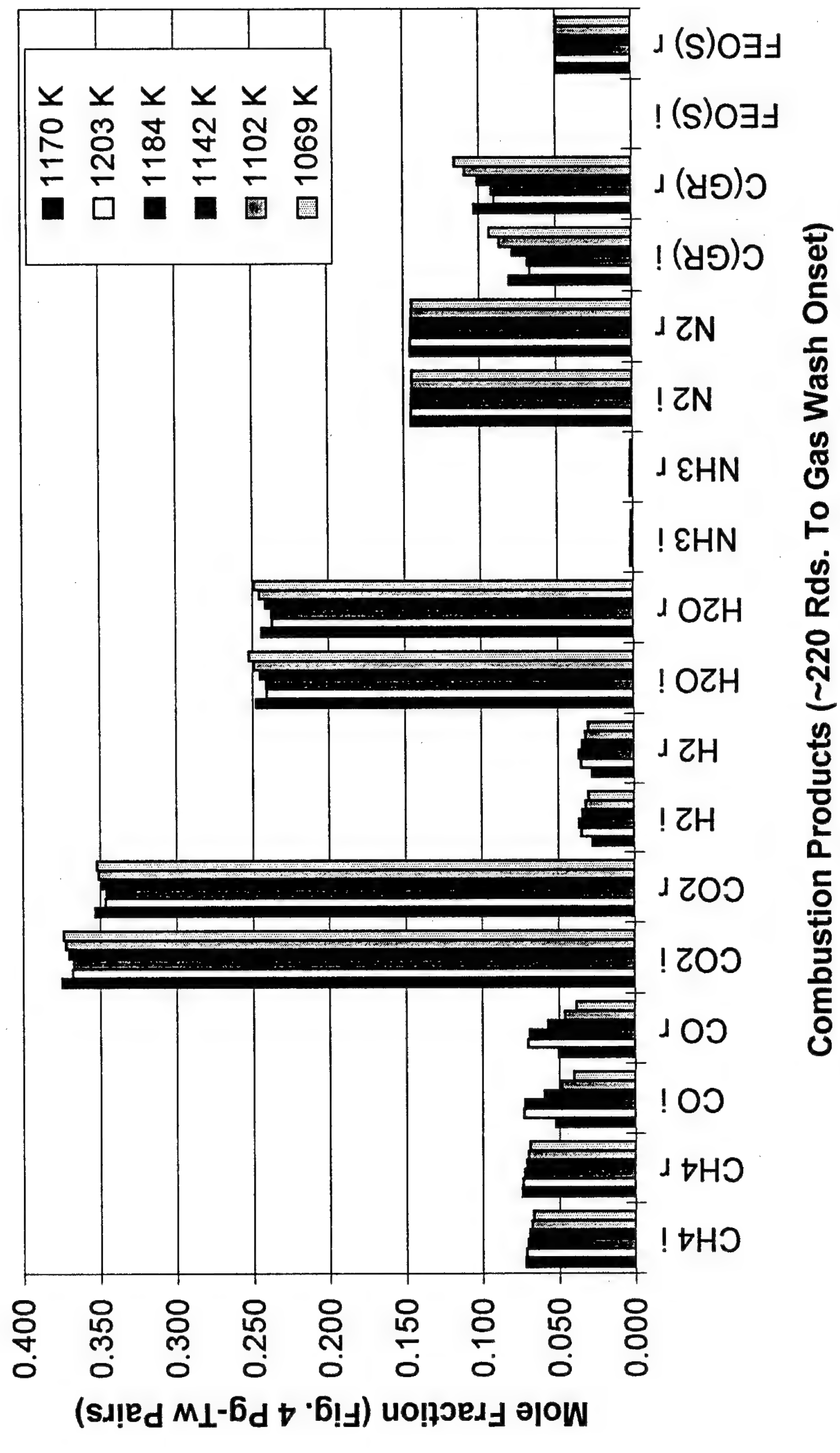


Figure 5 - CCET Inert & Reacting Cr/A723 Interface Comb. Prod.
For M829A2amb High Round Group At 27" RFT
Mole Fraction (Fig. 4 Pg-Tw Pairs)
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1142 K
1180 K
1164 K
1123 K
1082 K
CH4 i
CH4 r
CO i
CO r
CO2 i
CO2 r
H2 i
H2 r
H2O i
H2O r
NH3 i
NH3 r
N2 i
N2 r
C(GR) i
C(GR) r
FEO(S) i
FEO(S) r
Combustion Products (~460 Rds. To Gas Wash Onset)

Figure 6 - CCET Inert & Reacting Cr/A723 Interface Comb. Prod. - For M829A2amb Low Round Group At 27" RFT



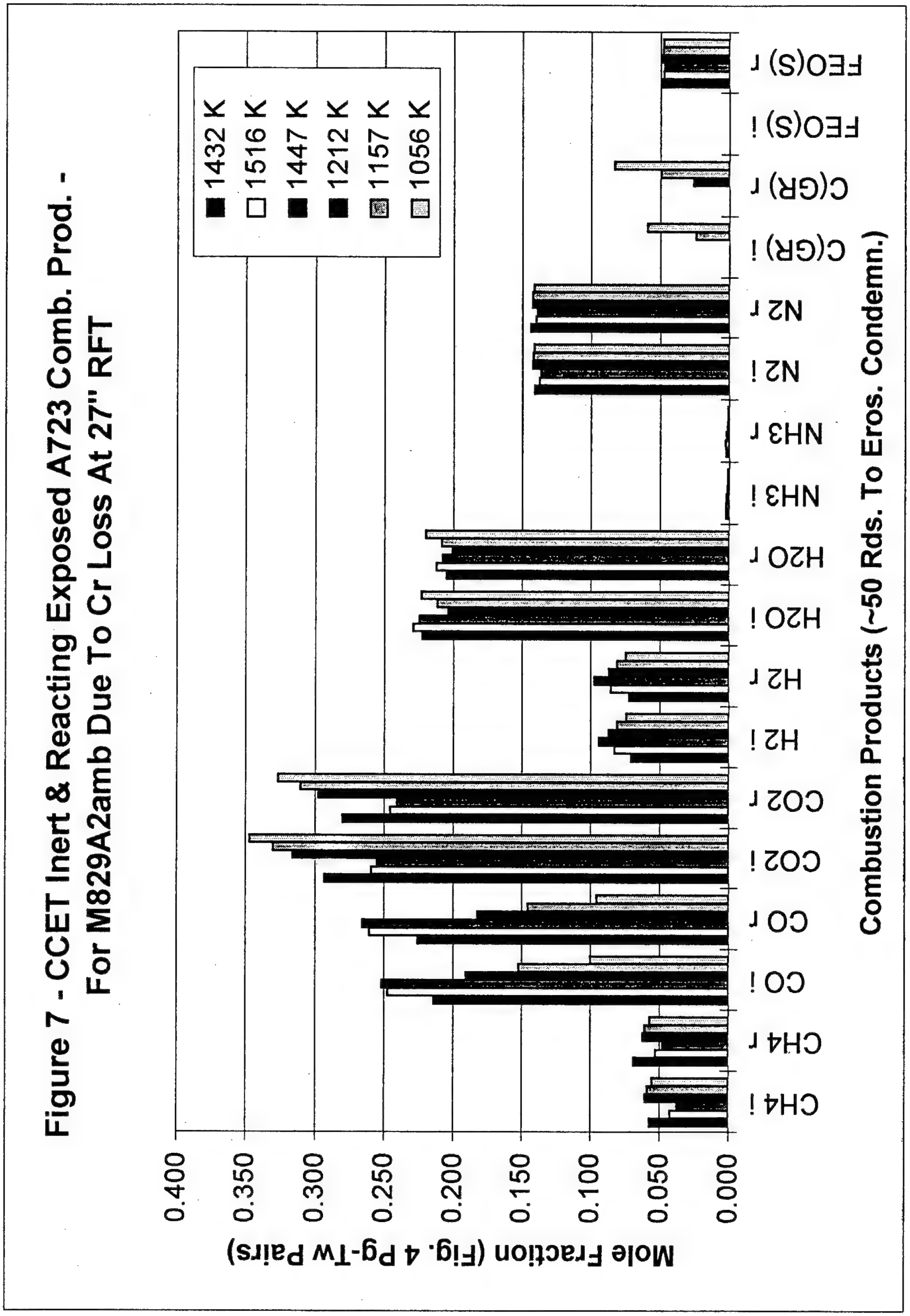


Figure 7 - CCET Inert & Reacting Exposed A723 Comb. Prod. - For M829A2amb Due To Cr Loss At 27" RFT

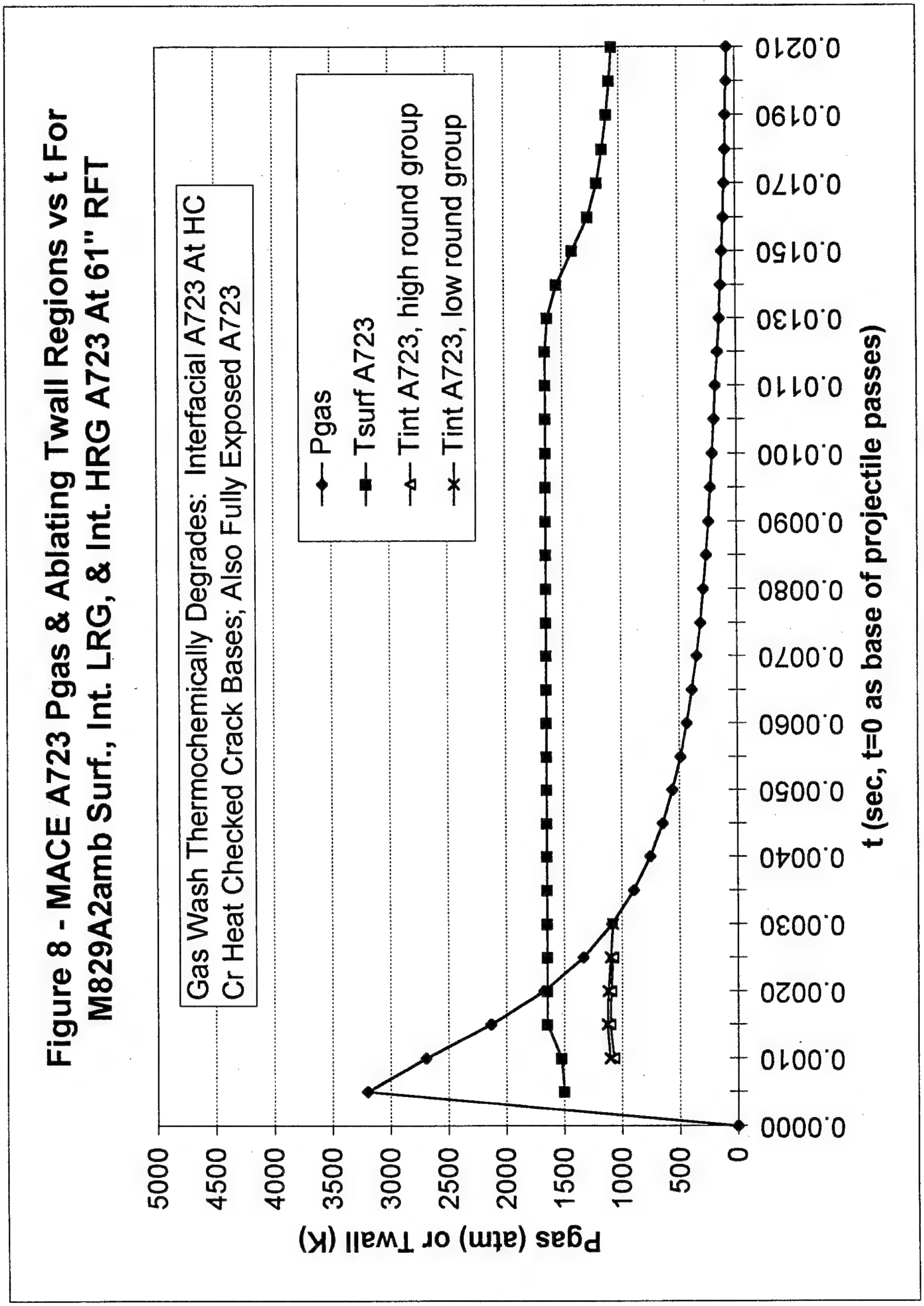
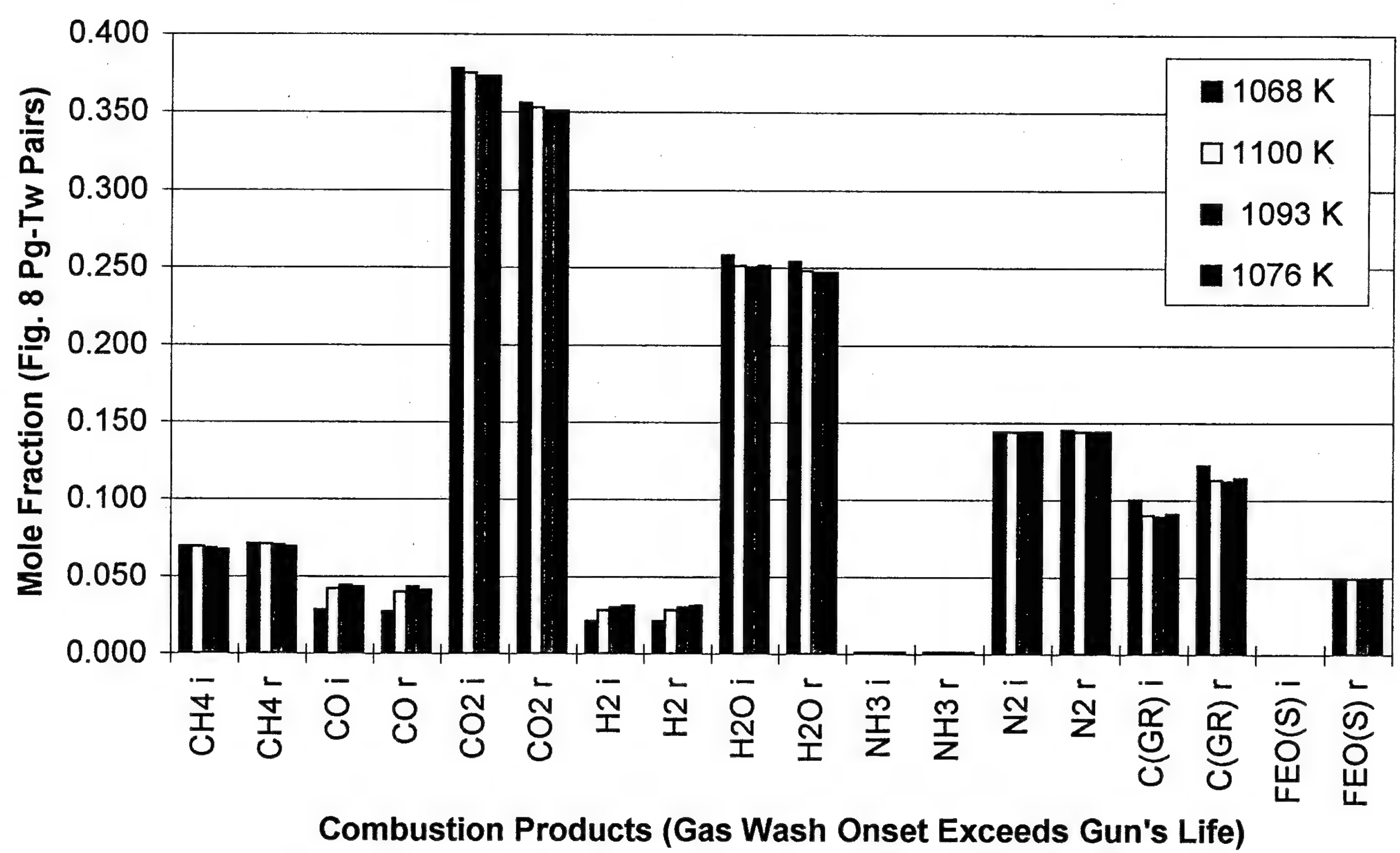


Figure 8 - MACE A723 Pgas & Ablating Twall Regions vs t For M829A2amb Surf., Int. LRG, & Int. HRG A723 At 61" RFT

Figure 9 - CCET Inert & Reacting Cr/A723 Interface Comb. Prod.
For M829A2amb High Round Group At 61" RFT



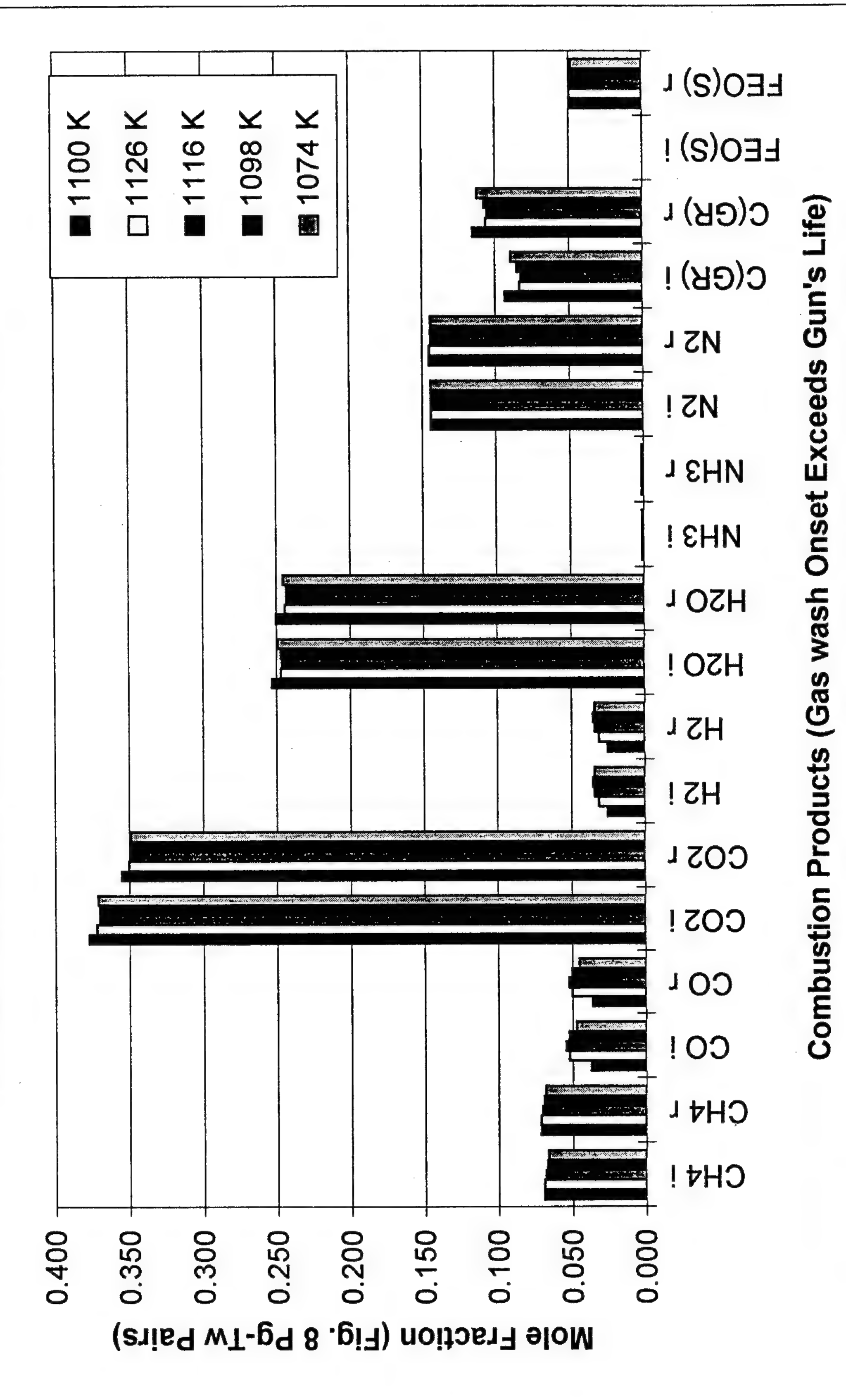


Figure 10 - CCET Inert & Reacting Cr/A723 Interface Comb. Prod. For M829A2amb Low Round Group At 61" RFT

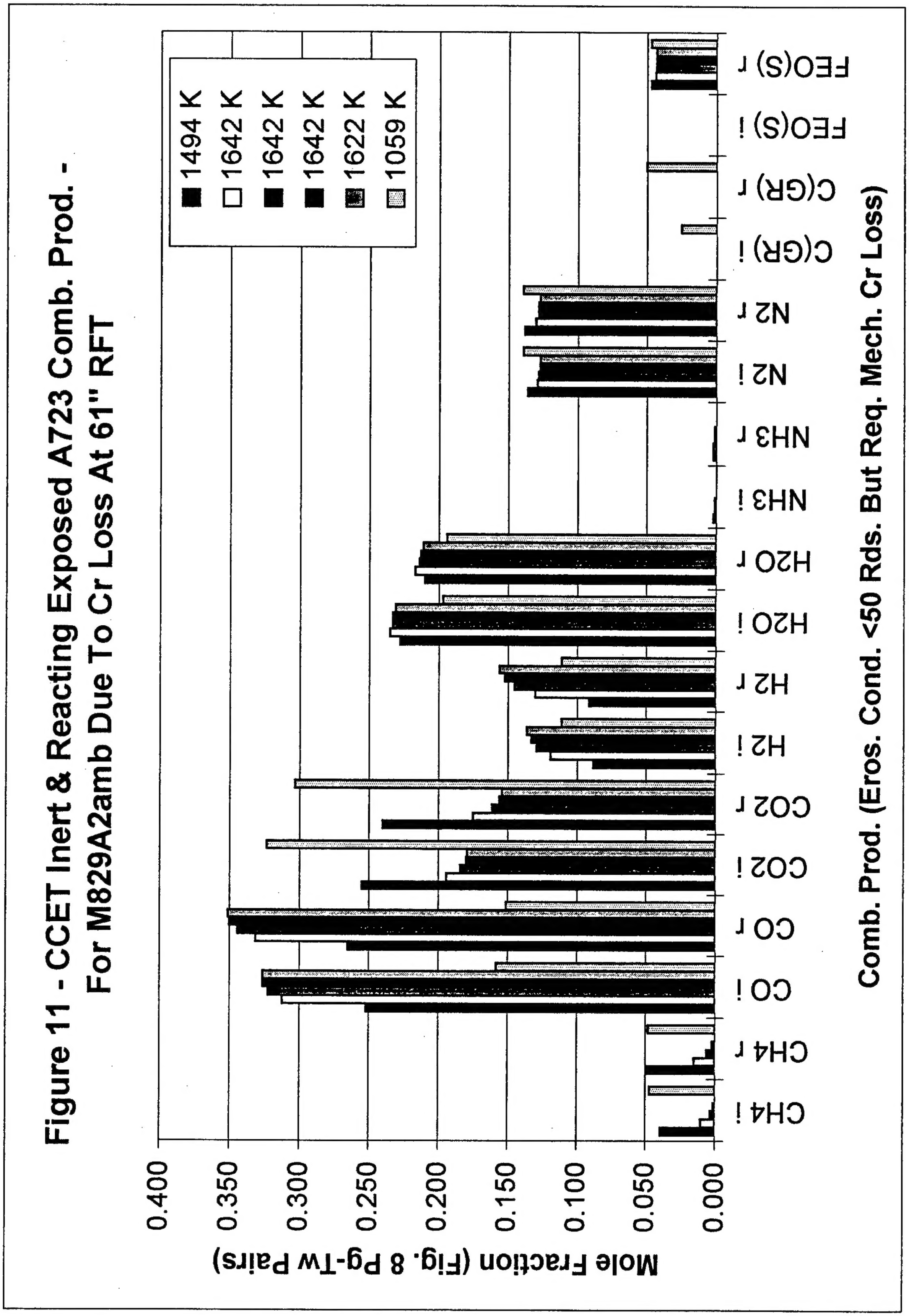


Figure 11 - CCET Inert & Reacting Exposed A723 Comb. Prod. - For M829A2amb Due To Cr Loss At 61" RFT

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